# Mobility Workshop

**December 4th, Windsor, ON**

Daimler Chrysler
Automotive Research and Development Centre

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John Mann, Director of Engineering, Daimler Chrysler Canada

**MOBILITY WORKSHOP**
**Daimler Chrysler Automotive Centre**
December 4th, Windsor, ON

The meeting was convened at the Daimler Chrysler Automotive Centre, Windsor, ON. The $30-million R & D Centre opened in 1996 and employs more than 120 Canadian engineers. The facility is a joint venture with the University of Windsor and the first co-operative automotive facility of its kind in Canada.

The facility was designed to develop new engines, conduct road simulation tests for Daimler Chrysler products and research alternative fuel technologies. The centre-located in a 14,864 $m^2$ building in the Rhodes Drive Industrial Park area of Windsor-draws on the co-operative working relationship between government, industry and education in automotive R& D. The automaker, the University of Windsor and Ontario's St. Clair College of Applied Arts and Technology have jointly developed a university course in automotive design.

The provincial and federal governments and the city of Windsor provided funding for the R&D centre. Chrysler paid for the facility's renovations and state-of-the-art research and testing equipment such as three road simulators, an engine performance analyser and CATIA computer design systems.

**PARTICIPANTS**
John Mann, Director of Engineering, Daimler Chrysler Canada
Jim Lanigan, Product Development Manager, Daimler Chrysler Canada;
Peter Frise, Daimler Chrysler Chair in Mechanical Design, University of Windsor, and
Andrzej Sobiesiak, Daimler Chrysler Chair in Alternative Fuels, University of Windsor.
Professor J. Douglas Boyd, Queen's University, Kingston, a specialist in materials-particularly microalloyed steels and composites; and
Professor Marc Ross, University of Michigan, who researches the efficiency with which a society uses energy (particularly in the automotive sector), the associated emissions and costs.

John Mann gave a presentation on the Daimler-Chrysler Automotive Research Centre, which is attached as Appendix A.

The presentation was followed by a facilitated group discussion on the factors that will influence the design and structure of the mobility sector in 2030-2050. Having set the scene for 2030-2050 the group was asked which fuels, materials, component production technologies, assembly technologies etc. would play an important role in this time frame. In addition, they were asked to identify the R & D priorities, technological gaps and the barriers to implementation of important mobility technologies. Although rail and air were touched on, the central discussion focussed on personalised transport in the automotive sector.

## THE DESIGN AND STRUCTURE OF THE MOBILITY SECTOR IN 2030-2050

It is expected, based on historical trends in North America, that motor-vehicle fuel use will increase in direct proportion to vehicle distance travelled. The general view of the automotive industry, expressed by the Chrysler team, is that emissions are likely to get a lot worse since increased mobility is directly linked with increases in the standard of living and population growth. Although the group recognised the importance of solving the Canadian problem they cautioned that we are dealing with a global context.

Several fundamental assumptions were made about the long-term future of the mobility sector in Canada. First, the number of vehicle kilometres travelled (VKT) will increase in proportion to the population. Second, people will want to retain the flexibility to travel where they want, when they want. It was felt that consumer demands would not be too different to those of today: convenience, range, affordability, quality and safety. The only change may be an increased emphasis on quality of life.

## FUTURE MOBILITY TRENDS

### LAND TRANSPORT

In response to predicted customer demands it was felt that personal vehicles would be similar to what they are today. There will probably be a variety of 2-6 passenger wheeled vehicles travelling on a roadbed with a cruise speed of about 100 km/h and a range between 300-500 km. Friction will still be used as the mechanism for steering control.

Congestion was identified as being a problem that carries a high environmental and financial cost. A variety of remedies could be seen to overcome the congestion problem. These remedies ranged from better urban planning to enable more walking, to sophisticated traffic control and crash avoidance systems. Consideration was given to commuter systems such as the station car model operating in Europe. Currently, commuting only accounts for 25% of the total vehicle kilometres travelled. In Canada it is likely that several large urban centres, notably Toronto, Vancouver and Calgary, are likely to double in size in the long term. The group cautioned that when urban centres grow past an optimum size they become undesirable places to live and start to depopulate. The smog-ridden Los Angeles basin, caused largely by vehicular emission pollution, was quoted as being a classic example of depopulation in action. Like Europe, North American population concentration could reach the "enough" point. Past a given level of population density, other forms of transportation-such as high-speed trains-become more widely used. Given the current population density, and the demographic predictions for southern Ontario, high-speed trains will be viable in the Windsor-Montreal corridor. Because of proximity to US markets, future Canadian industrialised growth may take place in southern Alberta, Manitoba and Saskatchewan in which case better cross-country infrastructure, such as a high-speed train link across the Prairies, will be a necessity.

Rail and shipping were identified as playing an important role in getting heavy goods vehicles (HGVs) off the road. Besides dealing with emissions from these vehicles, road degradation has to be considered. Heavy goods vehicles account for 25% of road damage and the damage increases to the power of 5 with weight. If the energy consumption, and emissions associated with road replacement and/or maintenance, are taken into account, the environmental cost of having HGVs on the road is very high. A trend towards locating suppliers closer to manufacturing sites to decrease transit distance and time is foreseen.

### RAIL

In the 2030-2050 time frame, it is expected that high-speed wheeled rail systems, probably electrified, will be in place in heavily populated and industrialised areas for passenger and goods transport. These trains would probably travel between 200-500 km/h and be used regularly over 200-1 000 km distances.

### AIR TRAVEL

Air travel will be much the same as today with perhaps increased use of high turbo fans and prop. fans. They will probably fly just subsonically at mach 0.98 or thereabouts and be used for stage lengths greater than 1 000 km.

## TECHNOLOGICAL CONSIDERATIONS FOR PERSONAL VEHICLES

In the long-term there will be great emphasis on lifecycle energy usage, enviromanagement and cost. To enable this type of lifecycle modelling the automobile has to be considered as a single integrated entity, which will require greatly increased use of design and simulation methodologies. Safety issues should be dealt with through regulations and design.

Fundamental physics is used as the guiding principle to improving vehicular performance. From this perspective *lighter is better,* lighter means easier to move, less fuel consumed and ultimately fewer emissions generated. However, light has its own barriers in terms of the materials that can be used. The group endorsed high-strength steel as the winner in terms of safety, formability and cost; aluminum, although inherently lighter, is a very high-energy-input material and suffers strength problems as well as having a high lifecycle cost; composites fatigue and have a high lifecycle cost as do plastics. Fuel consumption is not only affected by vehicle weight but also by drag and mechanical efficiency. A vehicle must be aerodynamically efficient to reduce drag and turbulence, thereby minimising fuel usage-however, this does not always mean that smaller is better. Mechanical efficiency is adversely affected by friction. A critical area of research is frictionless materials that obviate the use of lubricants thereby reducing emissions.

The important technologies identified by the group could be categorised into three areas: propulsion systems, fuel sets and the materials and processing technologies used for parts production.

## PROPULSION SYSTEMS

There is no dearth of different propulsion systems under development: internal combustion engines (ICEs); ICEs with alternative fuels; alternative engines; hybrid electric-fuel vehicles, all-electric battery vehicles; and fuel cell vehicles. In the quest to develop and select "clean" propulsion systems for tomorrow's vehicles two fundamental needs can be identified: the development of state-of-the-art techniques for measuring engine friction; and low-cost on-board instruments for emissions measurement.

The view, expressed by the representatives from Daimler Chrysler, was that there would still be a higher proportion of vehicles powered by internal combustion engines (ICEs) than other types of vehicles-whether fuel cell, electric or hybrid-in 2030-2050. It is predicted that hybrids will not have a high market share because they are inherently complex and suffer, for example, from decreased mechanical efficiency because they have a greater number of moving parts.

In terms of long-term emphasis the group favoured:

- ICEs based on homogeneous charge with self- or radical-ignition
- Fuel cell vehicles
- Hybrid vehicles (up to about 2010)

Electric vehicles were not considered viable because of the tremendous lifecycle energy consumption in making and disposing of batteries.

### 1. Internal Combustion Engines

Some background information on traditional ICEs and the scope for their improvement is given because these improvements in thermal and mechanical efficiency also apply to the ICE based on homogeneous charge with self- or radical-ignition that the group favoured as being a long-term "good bet."

#### Background on conventional ICEs – mechanical and thermal efficiency

Even with the two main kinds of internal combustion engines in use today: spark ignition engines and diesel engines; there is quite a bit of scope for improved performance.

In spark ignition engines, combustion occurs by means of a flame front that proceeds from the spark through the mixture of vaporised fuel and air. Variable power output is achieved by reducing proportionately both the fuel and the air admitted to the chamber. A throttle, which constricts the inlet to the intake manifold, regulates the amount of air, thus creating a partial vacuum as each piston is pulled out during its intake stroke. The throttle thus uses friction to control power, resulting in a major fuel-economy penalty. The fuel is introduced through controlled injection into the manifold. Only about $1/60^{th}$ as much fuel vapour as air is required. In spark ignition engines, the air-fuel ratio of the mixture is usually chemically correct, or stoichiometric, in that all the fuel and all the oxygen present could combine to form $CO_2$ and $H_2O$. In North America, catalytic converters oxidise any CO and hydrocarbons in the exhaust while removing $NO_x$.

The diesel engine utilises fuel droplets and high compression. Diesel engines are more efficient than spark ignition engines because they do not use a throttle, they have high compression ratios, and they operate with lean mixtures. Newer diesel engines are also overcoming the problems that have plagued them because of difficulties in limiting $NO_x$ and particulate emissions. However, diesel engines have a higher weight to power output than spark ignition engines but are more rugged and therefore tend to be used in commercial vehicles where low weight and very high transient power are not important but fuel economy is of consequence. For this reason, in North America the majority of engines currently in personal vehicles are spark ignition engines.

The thermal efficiency of current spark ignition engines is about 38%. There is scope for improvement up to 45-50% by using increased compression ratio, lean burn, recovery of work from the exhaust, faster combustion, effective control of working characteristics and control of valve timing and enhancement of breathing so that intake and exhaust are optimised at each engine speed. Improving thermal efficiency is an important goal. One way of achieving this goal is to develop successful lean-burn spark ignition engines. Another way would be to solve the environmental problems associated with the diesel engine and adopt direct-injection diesel engines. A third way would be to design a high-efficiency engine for different fuels such as hydrogen or methane.

Currently, the typical mechanical efficiency of engines, averaged over urban and highway driving is about 52%. It is lower for high-powered cars and higher for low-powered cars. The mechanical efficiency is zero when the engine provides no power output, with a near wide-open throttle the typical efficiency is about 90%. Mechanical efficiency is dependent to a large extent on friction. There are three kinds of friction involved in operating the engine: frictional forces experienced during pumping (moving the air and vaporised fuel into the cylinders and the combustion products out through the exhaust), overcoming rubber friction, and for driving the engine accessories. Unlike thermal efficiency where it is not practical to achieve an efficiency greater than about 50%, it may be practical to achieve mechanical efficiencies approaching 100%. The engine power output is the product of the mechanical and thermal efficiencies times the fuel energy input. (Overall engine efficiency = thermal efficiency x mechanical efficiency; for the average American car in 1993 the overall efficiency was ~ 20%!)

ICEs can be designed to run with many alternate fuels some of which are: reformulated gasoline and diesel with advanced emissions control; methanol; ethanol; gasohol; compressed natural gas (CNG) or liquefied natural gas (LNG); and hydrogen. There are also many alternative engines (alternative to four stroke and diesel): rotary; advanced two stroke; turbine; Stirling; and low heat rejection diesel. Research continues into ICEs using different fuels and alternative engines. In the 2030-2050 time frame the group felt that the propulsion mechanism of choice would be an ICE based on homogeneous charge.

**Advanced ICEs - Technologies for 2030-2050**

**Engines based on homogeneous charge with self- or radical-ignition**
Besides spark ignition and diesel compression, there is a third way to initiate burning of the fuel-air mixture in a piston-driven ICE. This technique uses engines based on homogeneous charge with self- or radical-ignition. Engineers can manipulate fundamental combustion parameters such as chamber geometry, valving and porting configurations, and engine cycle pressures to form a highly reactive chemical species that lower the fuel-air mixture's flashpoint so that modest compression makes it self ignite. These chemical initiators are then retained into the next cycle to start combustion, allowing the engine to run stably with no spark. Besides sparkless operation, the presence of these reactive (often oxygenated) hydrocarbon fragments in the mixture offers better gas mileage, lower exhaust emissions, and less cyclic variation. Combustion modelling will become increasingly more important to establish optimal operating conditions.

**Control devices to improve engine performance: VVT, CVT**
The key to maximising engine performance, particularly in gas fuel-direct engines, is to use new electronic control systems such as variable valve timing (VVT) devices that have some built-in intelligence. The control of when the intake valves open relative to the closing of the exhaust valves, is a relationship called overlap. Low or zero overlap is desirable for smooth operation at idle and reduced engine speeds. A lot of overlap at high engine speeds helps to generate horsepower.

Most current timing control systems are bimodal with one setting for ordinary operation, another for extra power. In contrast, continuously variable timing (CVT) allows smooth variation of the timing of the valves as the engine revs up. The result is a great improvement in maximum power and torque, higher all-around efficiency, improved emissions performance and some gain in fuel economy, as well as absolutely seamless operation. Some variable valve timing devices are also continuously variable devices.

**Catalytic combustion**
Development in highly active catalysts to optimise combustion processes is a technology that holds promise. The catalyst accelerates the combustion process. The result is better fuel economy.

**Post-combustion catalytic reduction**
Emissions, particularly diesel emissions, $NO_x$, can be mitigated by use of catalytic reduction of the exhaust emissions. The exhaust products, together with an enriched hydrogen or oxygen atmosphere, react on a catalytic surface. The result is that the nitrogen in $NO_x$ is replaced by either oxygen or hydrogen resulting in either nitrogen and oxygen release or nitrogen and water release respectively.

**Materials development for ICEs**
High temperature ceramic engines would be able to operate more efficiently at higher temperatures than conventional engines made from aluminum etc. They also afford

lighter weight. Ceramic materials still have to be developed that can withstand high-temperature operating conditions without cracking.

The mechanical efficiency of any ICE could be greatly increased by reducing friction. The development of frictionless materials, using either surface modification techniques or hybrid - perhaps layered materials-would enable increased efficiency while obviating the need for lubricants which vaporise and add to the emissions burden.

**2. Alternative propulsion systems**

Engines other than four stroke or diesel exist: rotary; advanced two stroke; turbine; Stirling; low-heat rejection diesel etc. Different hybrid electricity-fuel vehicles exist with differing emphasis: batteries and grid energy; fuel energy, engine operates near optimum, batteries used for storage; or fuel energy, but with "power storage" equipment (flywheels or capacitors). Electric vehicles exist that use different types of batteries: advanced lead acid; nickel cadmium; nickel-metal hydride; sodium sulphur etc.

Of all of these different systems the group placed long-term emphasis, after advanced ICEs, on fuel cells and hybrid vehicles- with the caution that hybrids tend to be complex and ultimately simpler systems will win out. It was thought that hybrid systems will be used up to about 2010 because they deliver the acceleration and range people are used to while respecting emissions and safety requirements. They will be hybrids with high power batteries-not charged from the grid since there are significant problems reaching a level of high energy density storage-used with IC engines or fuel cells. A one-speed hybrid could yield increased efficiency depending on the fuel used. The lifecycle energy costs to make and dispose of batteries are extremely high which makes electric vehicles non-viable. In addition to carrying high-energy and financial costs, batteries for EVs are heavy, have a short range and long recharging times.

**3. Fuel Cells**

Fuel cells are an important, rapidly evolving technology. Fuel cell vehicles are fuel-based and electrically operated. In contrast to an internal combustion engine fuel cells convert energy into power by electrochemical rather than thermomechanical means. They offer a propulsion system with zero-emissions.

Fuel cells create electricity efficiently, without combustion, without moving parts and without emissions. The efficiency of fuel cells is in the range of 80-95%- much higher than that of ICEs. They operate by converting the chemical energy of hydrogen and oxygen into electricity, the only by-product being water. The fuel cell needs a supply of high-purity hydrogen with an energy density that can compare with gasoline. On-board hydrogen could be stored as a compressed gas or perhaps eventually in liquid form. Research continues on developing "plug and play" cartridges with hydrogen contained in carbon nanotubes or fullerines or glass microspheres. Metal hydrides are being investigated as a safe way of storing hydrogen chemically for on-board release. The alternative to on-vehicle storage of hydrogen is to produce it on-board by reforming hydrogen-rich fuels–such as gasoline, methanol, or methane–or by water electrolysis, if and when electrolysers become sufficiently small and light to be viable. It is becoming

cost effective to use electrolysers for small-scale production of hydrogen which is compressed and then stored on-board.

A number of different fuel cell designs exist, each with a different set of advantages, disadvantages and applications. The most promising for light vehicle use are primarily proton exchange membrane (PEM) fuel cells. PEM fuel cells are fairly compact and operate at low temperatures. However, there are some challenges to overcome. To make the fuel cell cost competitive further reductions in the amount of platinum catalyst are needed and the cost of the membrane has to be lowered. The performance of the cell membrane has to be improved i.e. made thinner to increase the power density of the fuel cell without compromising its integrity. Finding a way to keep the membrane moist without having water build up on the cathode needs to be addressed. The overall performance of the air compression system in terms of its energy use and size should be optimised. There is also a pressing need to decrease the size, weight and cost of the fuel cell stack which is dependent on the plates used to stack and hold the individual fuel cells in position.

Fuel cells are only one part of the fuel cell vehicle. The electric drive train is usually made up of an electric motor, a power electronics system and a transmission. The drive train together with the other system components such as: hydrogen storage vessels; air compressor to deliver oxygen to the fuel cell; fuel cell cooling system; and water management system all have to work efficiently as a single unit. In the case of a fuel cell vehicle with an on-board reformer, the reformer has to be a part of the integrated system. One of the major drawbacks of the fuel cell vehicle is the sheer volume and weight of its component parts.

When hydrogen storage and production devices and fuel cells reach a level of cost effective maturity, fuel-cell vehicles will become a serious competitor in the marketplace. For now they are best suited for buses and tracks. In the interim some consideration should be devoted to hybrids to satisfy increasingly stringent emissions regulations.

## FUEL SETS

In early seventies, during the energy crisis, energy security was the main driver. Today environmental concerns are the driving forces. In 2050 the group thought that security of supply would be the main issue again.

It was suggested that an intelligent appraisal should be made of the fuel needs for stationary use i.e. residential or industrial versus mobile use. Arguably, stationary sources could make use of renewable sources of energy (including nuclear energy if there could be a change in public perception), or electricity generated from fuel cells. However, vehicles, which require fuels of high power density, could use fossil fuels produced by clean technologies that have been reformulated to decrease emissions.

In terms of energy and power density there is a hierarchy of fuels. Gasoline and diesel have the highest power density followed by alcohols (methanol/ethanol etc.), natural gas, propane and hydrogen respectively.

In the past 20 years huge strides have been made in emissions reduction from gasoline, so much so that further work on emissions has almost reached the point of diminishing return. It was stated that gasoline technology would still evolve continuously. Gasoline can be improved by reformulation and will be difficult to beat from the aspect of power density.

New diesel fuels are becoming cleaner and have improved fuel economy over gasoline. However, some concerns still remain about diesel particulate emissions < 2 μm that are considered to be carcinogenic. In time it should be possible to mitigate this problem.

Methanol and ethanol are renewable fuels that work in existing engines with some minor modifications. They are not as efficient as gasoline and they are more corrosive to engines.

Natural gas, either in its compressed form (CHG) or liquefied form (LNG) produces fewer emissions than gasoline. The infrastructure costs-refuelling stations-are high. CNG requires a large storage tank that limits trunk size.

Hydrogen will become a viable fuel when problems associated with storage and on-board production are solved (see under fuel cells). In the interim, hybrid fuels are being researched such as gasoline/hydrogen mixtures or diesel/hydrogen mixtures with the gasoline or diesel component being highest under high load conditions. Two tanks would be required for separate storage of the component fuels.

The group place emphasis on development of reformulated liquid, high-energy density fuels such as reformulated gasoline, hybrid fuels such as hydrogen mixes followed by all alternative fuels. It was suggested that some effort should be devoted to in-vehicle and at source carbon capture technologies.

## MATERIALS AND MANUFACTURING TECHNOLOGIES

The energy consumed in producing a car is equivalent to 4.5 years of operation for the average vehicle. This emphasises the importance of lifecycle analysis modelling to minimise GHG emissions and energy consumption during production. It also puts fuel consumption into context.

There is a real need to consider the car as a complete entity not just the sum of many parts. Determining how the parts will all work together and how changes in one operating parameter will affect the others is crucial in optimising the overall production process. It will require greatly increased use of simulation and numerical modelling techniques especially related to computational fluid dynamics (CFD) and thermofluids to integrate air flow, heat flow and combustion. CFD will allow greatly improved

component design e.g. manifolds, engines etc., as well as ensuring good aerodynamic response for the overall vehicle.

There should be a focus on design for manufacturing and assembly (DFMA) techniques to minimise energy consumption and optimise quality control. Flexible, remotely controlled, robotic assembly using, for example, fixtureless assembly and advanced joining techniques will probably become the norm in the long term. Solid free-form manufacturing of parts and rapid prototyping for rapid die manufacture will become increasingly important. Quality control through on-line process control relies to a great extent on sensors. Microprocessor-based sensors and controls and the concept of intelligent manufacturing are the keys to process optimisation.

Components are made from materials. Selecting or designing the "right" material for a component and integrating the material design with the chosen manufacturing process is key in producing a quality product. Engines, drive trains and suspension systems are examples of automotive systems that would benefit from integration of materials design with product design. Methodology for selecting the "right"' material, which includes the energy required to make the material itself, should be developed. The development of mathematical models for microstructural control and engineering property prediction of materials will play an important part in enabling materials selection and design.

The ability to select and design materials to meet specific property requirements allows materials to be tailor-made. Tailor-made materials are usually referred to generically as advanced materials. Smart materials have built-in sensors; intelligent materials can not only sense but actuate as well. Many designer materials are made from two or more different materials. An understanding of the interfacial interaction of these materials is vital in determining the integrity of the hybrid or composite.

Vehicles have a requirement for many different materials. The overall drivers are lightweight and crashworthiness. The group predicted that high-strength steel will still be "alive and well" in the 2030-2050 time frame on the basis of its strength-to-weight ratio, fatigue properties and ability to absorb energy on impact. Many other materials were identified as being important in the long term-they are listed below.

Examples of materials for the automotive industry of the future

- lightweight and crashworthy materials: low weight, low energy input, low cost e.g. high-strength steel; aluminum and magnesium, plastic composites
- advanced alloys e.g. electrorheological materials that change viscosity with changing current - their damping factors and spring constants change -this can be used to advantage in can be used in springs, suspension systems or clutches
- composites - metal matrix, polymeric, plastic -composites are designed to combine two dissimilar materials (metals and non-metals in the case of a metal matrix composite) to produce a high-performance material with the best properties of both and none of the worst
- crack-resistant, high-temperature ceramic materials for engines
- hybrid materials-layered materials

- surface modified materials-for example:
- self-lubricating or frictionless materials to render lubricants obsolete and reduce component wear
- paintless materials-use of surface modification techniques to produce corrosion-resistant materials that can be coloured to specification and do not need to be painted
- nano-modified (atomic-scale construction) material surfaces for niche application such as increased wear resistance or electrical conductivity, other surface modification techniques such as ion implantation will become increasingly important also
- smart and intelligent materials with built-in sensor and actuator mechanisms
- shape memory alloys that reconfigure into their original shape after deformation.

**Infrastructure issues**

There is a need to reconsider the way in which electricity is generated. Nuclear power was addressed as being a viable way of producing power for stationary use. Effective radioactive waste and heat disposal as well as a change in public perception of the nuclear industry would be required.

A new fuel infrastructure may have to be considered if, for example, hydrogen becomes the fuel of choice in the long-term.

Road improvements and new roads are needed; high-speed commuter and goods rail links are needed.

$CO_2$ sequestration at power plants and factories need to be addressed in addition to focussing some effort on on-board vehicular sequestration.

**General remarks**

A support mechanism is needed for applied research, which leads to relevance and renewal in research and curricula. There is a pressing need for graduates who will be useful to industry.

Canada is in poor shape due to lack of relevant R & D programs and poor levels and effectiveness of technical education. Lack of educated people is Canada's biggest problem. In a North American study, Ontario was 58th out of 60 in providing funding for higher education. The question " do we really want to compete with Arkansas?" was posed!

Canada needs to identify critical industries for its own use and for global export. It needs to find its international and national niches. Steel, artificial intelligence and fuels were suggested as being examples of three areas where Canada has considerable expertise. Building on these areas it is essential to develop a capacity for innovation to remain

competitive in the global marketplace. A balance must also be found between the desire to disseminate/share information on climate change for global benefit and the need to protect intellectual property to remain competitive.

**The Bottom Line**
Automotive R & D Priorities for 2030-2050

*Invest in Education*
*Identify National and International Niches Based on Canadian Expertise*

**INFRASTRUCTURE**
- Smart highway systems, crash avoidance systems
- Road improvements
- High speed rail links
- Nuclear research to provide energy for stationary use
- Fuel infrastructure for alternative fuels such as hydrogen
- On-site carbon dioxide sequestration at power plants, factories etc.

**PERSONAL VEHICLES**
- Lifecycle enviromanagement

**Propulsion Technologies**
- Internal combustion engines
  - Engines based on homogeneous charge with self- or radical-ignition
  - Control devices to improve engine performance: VVT, CVT
  - Catalytic combustion
  - Post-combustion catalytic reduction
  - Materials development for ICEs
- Fuel cells and hydrogen storage

**Fuel Sets, Carbon Management**
- high energy density reformulated liquid fuels such as designer gasoline
- hybrid fuels e.g. hydrogen and gasoline, hydrogen and diesel
- other alternative fuels
- on board $CO_2$ capture

**Materials and Manufacturing**
- Greatly increased use of simulation
  - Materials/process/part design integration
  - Modelling of material engineering properties through microstructural control
  - Computational fluid dynamics (CFD): integration of air flow, heat flow and combustion, overall vehicle aerodynamics
  - Design of manufacturing and assembly techniques

- Power electronics for systems control
- Rapid prototyping primarily for die manufacture

**Materials and Manufacturing** (continued)

- Designer Materials
  - Lightweight and crashworthy materials
  - High temperature, crack-resistant ceramics for lightweight engines
  - Advanced alloys, hybrid materials, composites
  - Smart and intelligent materials
  - Self-lubricating (frictionless) materials, paintless materials, materials with electro-rheological properties, shape memory alloys etc.

## Appendix A

### Overview of the Daimler Chrysler Automotive Research and Development Centre (ARDC)

John Mann, Director of Engineering, Daimler Chrysler Canada

**Automotive Industry in Canada**

- contributes 11.5% to the manufacturing GDP
- has annual sales of $72 B
- has autosales of $50 B
- accounts for 1 in 7 jobs in Canada, 1 in 6 jobs in Ontario
- yields a trade surplus of $30 B
- pays $20 B in wages

**Status of Automotive R and D in Canada**

- all R & D conducted by non-Canadian parent companies
- deteriorating Canadian technology base
- little relevance of academic research to industry
- stagnant apprenticeship program
- Canadian investment in R & D only 0.2% of sales revenue and is primarily carried out by Tier 2 parts suppliers.

**Key Strengths of the Daimler Chrysler Automotive R & D Centre**

- adjacency of Daimler Chrysler/University of Windsor
- Windsor is the automotive capital of Canada, directly across the US border from Detroit, the automotive capital of the US
- Windsor is the focal point for Canada/US commerce
- both Chrysler and Univ. of Windsor have strong R & D capability
- the University has a strong program focus on automotive
- automotive sector is the number 1 employer in Windsor

**Benchmarking Process undertaken by ARDC**

*"If you always do what you always did you'll always get what you always got."*

In its quest to attain excellence, Daimler Chrysler undertook a worldwide benchmarking study to determine the best innovation practices. These practices were adopted as the cornerstone of the Automotive R & D Centre's philosophy. The study considered:

- needed improvements
- the best R & D practices
- the best human resources practices
- the best educational practices
- key success factors

**Benchmarking Objectives**

The benchmarking study focused on the following topics:

- curriculum development
- collaborative R & D
- governance
- financial relationships
- continuous improvement
- government involvement

**Benchmarking Findings**

Greatest success is achieved through:

- industry collaboration with technical institutions
- joint industry/university curriculum development
- industry participation
- listening with an open mind
- creating WIN/WIN situations

**ARDC Goals**

- create more R & D career opportunities
- forge strong R & D initiatives-based on future anticipated needs
- establish strategic professorships
- develop new technical curricula
- provide industrial experience for students

**ARDC Status**

- officially opened May 30, 1996
- investment from federal and provincial governments was $20 M; Chrysler's contribution was $30 M totalling $50M. Chrysler will double this investment in the 1999. The annual operating budget for the centre is ~ $ 20 M.
- two Chrysler/NSERC Chairs have been created and staffed at the University of Windsor
- the centre created 100 new high tech. jobs
- the centre has provided industrial experience for over 50 students.

**ARDC Facility**

- open concept engineering office
- has video conferencing
- live link to other Chrysler facilities via an integrated high speed network
- vehicle durability lab.
- engine dynamometer lab.
- materials lab.
- fabrication and prototyping facility
- 7.5 MW substation

**Chair of Mechanical Engineering Design**

- responsible for development of a degree program in mechanical engineering design
- responsible for development of a research program in mechanical engineering design methodology
- acts as a bridge to college (St. Clair) mechanical design program-fulfils a need for a two-way continuum between college and university programs

**Chair of Alternative Fuels**

- staffed in July 1998
- liaison position between University/Chrysler/St. Clair College
- R & D focus primarily on analysis; simulation and experimental research on liquefied petroleum gas (LPG), compressed natural gas (CNG) and alcohols.

**Chrysler Centre for Imaging Research**

- enables characterisation of advanced materials
- R & D carried out on fundamental acoustic science
- new acoustic methods developed for nondestructive evaluation (NDE) of automotive parts and processes
- has expanded capability of centre
- allows better quality control

**Computational Fluid Dynamics (CFD)**

- CFD is an important future technology-computational tools have enabled a decrease in automobile time to market (design to production) from 5 years to 2 years. (Speed to market is crucial in the automotive business)
- air flow methodology is well developed-however, the link between heat flow and air flow remains to be made.

**Mechanisms for University Work Terms at ARDC**

- undergraduate coop. program
- post-graduate internship
- masters students
- research sabbaticals for university staff

**ARDC Benefits to Chrysler**

- modern, flexible research centre
- leads to better educated personnel in workforce
- NSERC research chairs
- enhanced image and profile in Canada
- relevant educational program
- coop students workterms

**ARDC Benefits to University if Windsor**

- NSERC chairs and associated status
- undergraduate /graduate research programs
- industrial experience for students
- enhanced university image and profile
- linkage to major industry
- degrees that employers value
- lab. space for automotive research activities

**ARDC Benefits to Canada**

- modern high-tech. facility that has created jobs
- increased technical base in Canada
- increases linkage between education and industry
- two-way knowledge transfer process
- relevant R & D program

**"If you don't make dust you eat dust"**